Construction Productivity Analysis of Pre-Cast and Conventional Cast-In-Situ Projects

A Case Study in Malaysia

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Abstract

Advantages of pre-cast technology in the construction of commercial, residential and institutional buildings are well documented in literature. However, the acceptance of this technology in Malaysia is relatively low with few projects being constructed with pre-cast components. The objectives of this paper are to measure labor productivity in construction, to examine productivity indicators between pre-cast and conventional Cast-In-Situ (CIS) methods, and to explore areas of improvements to promote adoption of pre-cast technology in Malaysia. Data on construction labor productivity are collected using questionnaires, interviews, and observations at the construction sites. Based on statistical analysis performed in this paper, it is concluded that pre-cast method is better than conventional CIS method in terms of construction labor productivity, time to complete a project, variability of construction activities, and loss of efficiency during the construction process. Baseline productivity, unit rates for pre-cast components and correlation of the productivity factors to construction labor productivity are presented as well.

Keywords

Construction Labor Productivity, Conventional Cast-In-Situ, Pre-cast, Value and Benefit

Introduction

Construction acts as a stimulant to Malaysia's development. The construction industry also constitutes an important element of the Malaysian economy. Although construction industry accounts for a small percentage of the country's GDP in year 2002 (Malaysian-German Chamber and Commerce and Industry (MGCC), 2004), it is a strong growth push industry because it has extensive linkages with more than 140 upstream and downstream industries, construction related manufacturing industries such as basic metal products and electrical machinery (Badir et al., 2002; Ministry of Finance Malaysia, 2003; Construction Industry Development Board Malaysia, 2003).

This paper describes a comparative productivity study between a few projects to be built using pre-cast technology and conventional CIS method. Three project sites are studied: two using pre-cast technology and one using conventional CIS method. The two sites using pre-cast technology are Akademi Binaan Malaysia (ABM) located at Sintok, Kedah and Akademi Audit Negara (AAN) at Nilai, Negeri Sembilan; while the one using conventional CIS method is SIRIM laboratory located at Bukit Jalil, Selangor.

Labor productivity using pre-cast and conventional CIS construction methods is studied. The measurements are focused on four structural components: beam, column, wall and slab. Data on construction labor productivity are collected using questionnaires, interviews, observations, video camera and secondary data collection such as site daily reports, monthly progress reports, project schedules, structural drawings, and other relevant materials. The research methodology for data collection is presented in Figure 1.

In the next sections, data collected from the sites and secondary reports are analyzed and the factors/indicators that influence the labor productivity are determined statistically. Comparison on the labor productivity for the two construction methods is demonstrated. Finally, conclusion and recommendation are presented for similar projects in Malaysia.

Productivity Analysis of Pre-Cast Construction Method

Overview

Labor productivity at two project sites for pre-cast construction method is presented. Two office projects utilizing pre-cast construction method are studied, i.e. ABM and AAN projects. At the construction sites, pre-

fabricated or pre-cast structural components are installed piece by piece. The installation of different structural components required different resources (labors) and duration.

Daily Productivity

Figures 2 and 3 show the daily and baseline productivity for ABM and AAN projects. It is important to note that the definition of productivity rates is used in this research. The common method to define productivity is output divided by input. Yet, the convention used for the productivity rates or values is input divided by output, i.e. work hours per piece of standard item. In the figures, it can be seen that there are a few peaks with low productivity values.

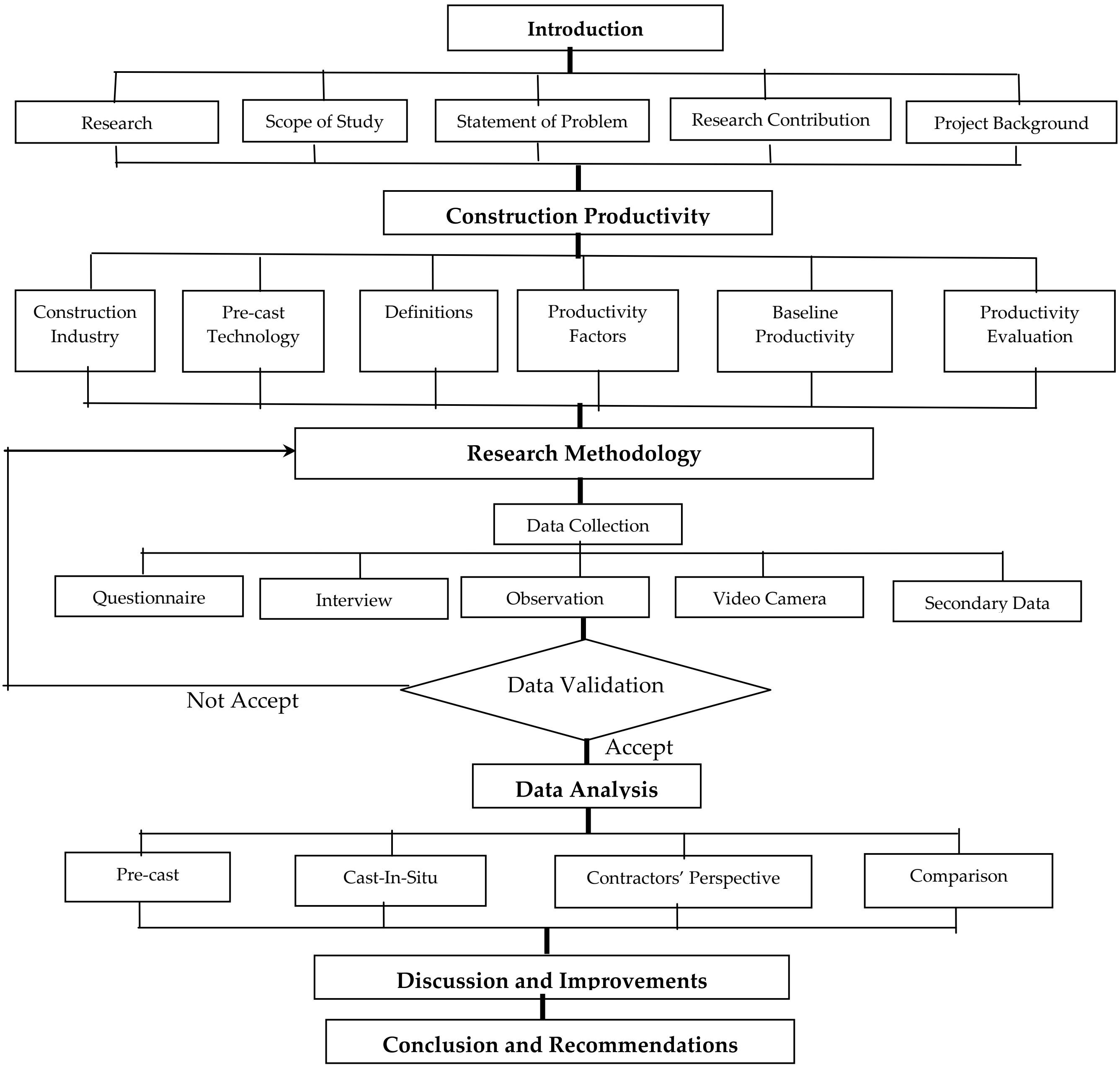

FIG. 1 RESEARCH METHODOLOGY

Baseline Productivity

Baseline productivity, an estimate of the best productivity that a contractor could achieve on a particular project (Thomas, H. R. and Zavrski, I., 1999), can be calculated for each data set by determining the work hours and quantities installed on days when there are no changes or rework, disruptions, or bad weather reported.

The baseline is determined using the following steps (Thomas, H. R. and Zavrski, I., 1999):

i. Determine 10% of the total workdays.

ii. Round this number to the next highest odd number; and this number should not be less than 5. This number *n* defines the size of (number of days in) the baseline subset.

iii. The contents of the baseline subset are selected as the *n* workdays that have the highest daily production or output.

iv. For these days, make note of the daily productivity.

The baseline productivity is the median of the daily productivity values in the baseline subset.

The bold lines in Figures 2 and 3 indicated the baseline productivity for the project. Baseline productivity is based upon the best output possible. It is assumed that without any disruptions, the contractor will be able to perform at this productivity rate. The baseline productivity for ABM project is 0.47 wh/pc of slab and 0.40 wh/pc of plank for AAN project. Note that slab and plank are considered as standard items in ABM and AAN projects as they are used the most at the sites.

Cumulative Productivity

Figures 4 and 5 show the graphs of cumulative productivity versus workdays for ABM and AAN projects. Cumulative productivity is an accumulation of all the recorded work hours divided by the total quantities of the installed structural components. It is calculated by dividing the cumulative work hours by means of the installed cumulative quantities.

Thus, learning curve theory does not apply to ABM project due to age group of workers who always used to work with CIS method. From the beginning to workday 65, the cumulative productivity was about the same and it can be seen that there was no great improvement in labor productivity. On the other hand, labors' performance on AAN project was improved over the 60 workdays.

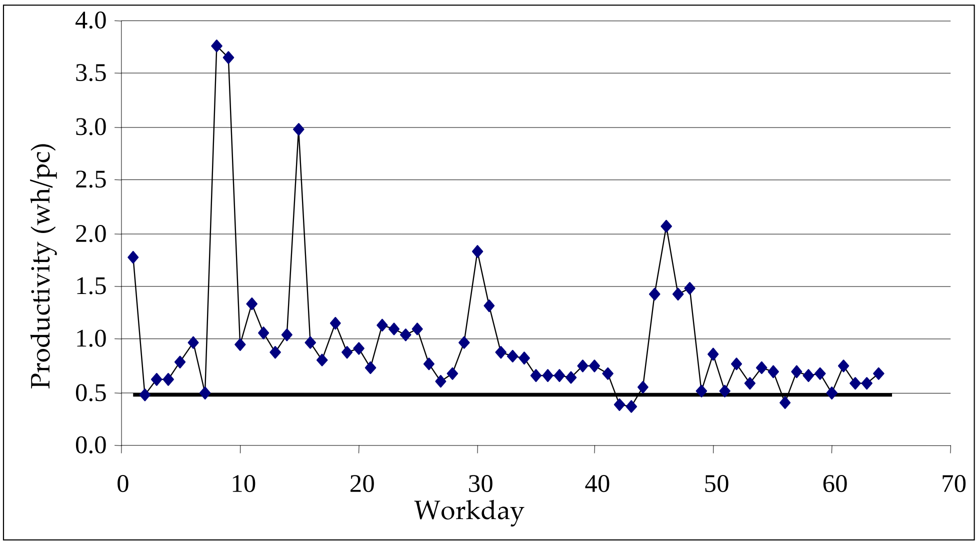

FIG. 2 DAILY AND BASELINE PRODUCTIVITY FOR ABM PROJECT

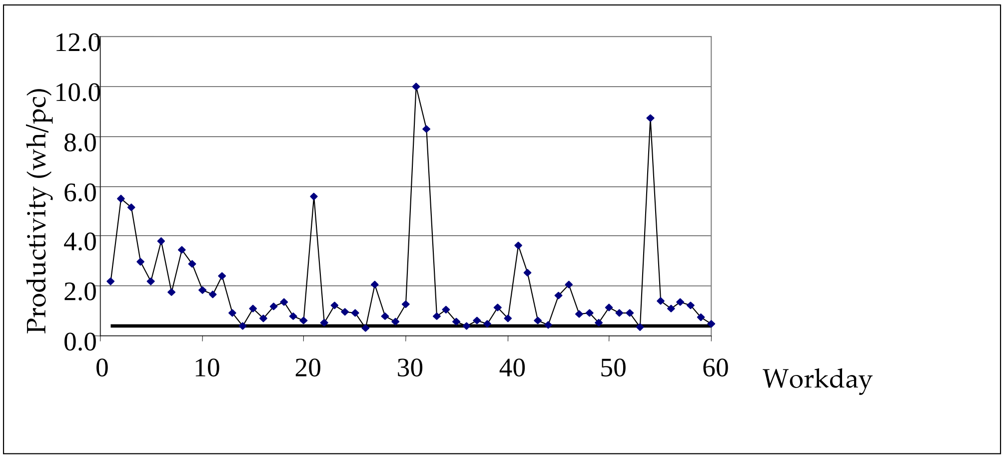

FIG. 3 DAILY AND BASELINE PRODUCTIVITY FOR AAN PROJECT

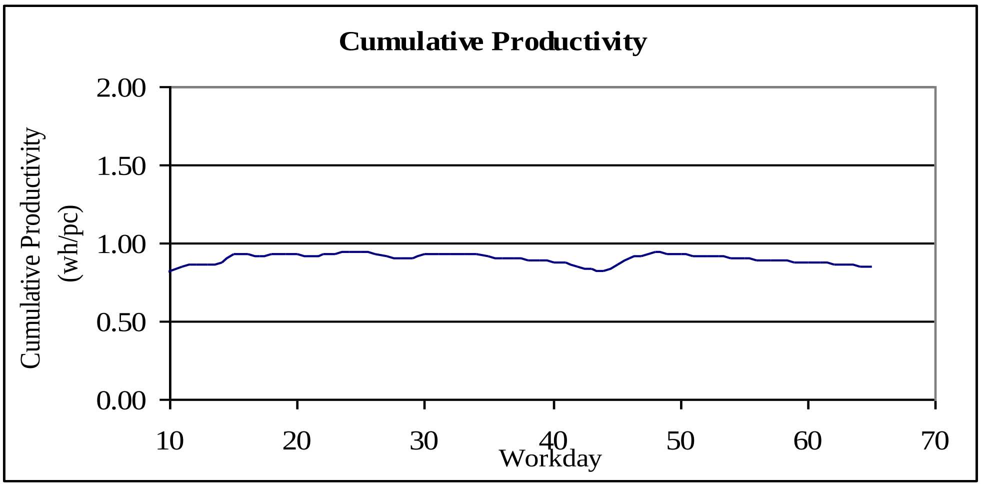

FIG. 4 CUMULATIVE PRODUCTIVITY FOR ABM PROJECT

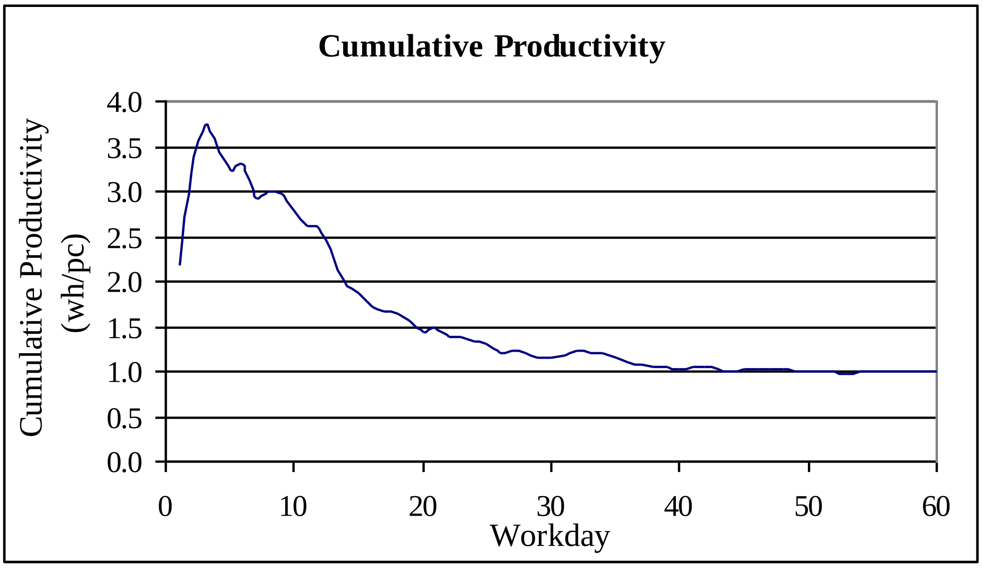

FIG. 5 CUMULATIVE PRODUCTIVITY FOR AAN PROJECT

Unit Rates

TABLE 1 UNIT RATES OF PRE-CAST COMPONENTS FOR ABM PROJECT

Component	Unit Rate (minute/piece)
Column – 3m	15.86
Column – 6m	55.40
Beam	30.89
Slab	**6.20**
Wall – Short	9.54
Wall – Long	3.56

Unit rates, the productivity (work hour per piece) obtained from projects, are measured in terms of work hour per piece of every different component. and needed in order to calculate the conversion factor (Thomas, H. R. and Karl, A.R., 1997; Thomas, H. R. and Napolitan, C. L., 1995; Thomas, H. R. and Raynar, K.A., 1997; Thomas et al., 1999; Thomas, H. R. and Zavrski, I., 1999). Tables 1 and 2 summarize the findings for most structural components that are installed at the sites.

TABLE 2 UNIT RATES OF PRE-CAST COMPONENTS FOR AAN PROJECT

Component	Unit Rate (minute/piece)
Slab – HCS	10.50
Slab – Plank	**7.12**
Beam	18.74
Column	25.94
Wall Panel – Small	14.80
Wall Panel – Large	24.11
Staircase	71.83
Balcony	22.90

Conversion Factor

Conversion factor shows how much difficult or with longer duration an item is to install the project

compared to the standard item (Thomas, H. R. and Zavrski, I., 1999). Pre-cast components used in these two projects are different in sizes and types and the quantities of each component are measured in various units. Thus, the productivity of all workers expressed as an equivalent output can be calculated for the same standard item during each period regardless of the type of performed work. The equation of conversion factor is presented below.

$$\text{Conversion Factor}_i = \frac{\text{Unit Rate for Item } i}{\text{Unit Rate of Standard Item}} \quad (1)$$

Conversion factors convert the quantities of one item to equivalent quantities of another item, which is the standard item. Standard item for both projects are selected as the item that occurs most frequent in the construction process. Thus, the standard item for ABM project is Hollow Core Slab, whilst for AAN project is Plank Slab. Conversion factors of every component for the two projects are listed in the Tables 3 and 4 below.

TABLE 3 CONVERSION FACTOR OF PRE-CAST COMPONENTS FOR ABM PROJECT

Component	Conversion Factor (Quantity of Standard Item)
Column – 3m	2.56
Column – 6m	8.94
Beam	4.98
Slab	**1.00**
Wall – Short	1.54
Wall – Long	0.57

TABLE 4 CONVERSION FACTOR OF PRE-CAST COMPONENTS FOR AAN PROJECT

Component	Conversion Factor (Quantity of Standard Item)
Slab – HCS	1.48
Slab – Plank	**1.00**
Beam	2.63
Column	3.64
Wall Panel – Small	2.08
Wall Panel – Large	3.39
Staircase	10.09
Balcony	3.22

Correlations of Pre-cast Construction Productivity Factors

Data collected from the two pre-cast construction sites, i.e. ABM and AAN projects are analyzed using correlations analysis. Table 5 shows the correlation of determinant, R^2 values as the results of the analysis.

TABLE 5 CORRELATION OF DETERMINANT, R2 VALUES FOR PRE-CAST CONSTRUCTION PRODUCTIVITY FACTORS

Project	AAN	ABM
Factors	Correlation of Determinant, R^2	Correlation of Determinant, R^2
Unloading Duration	0.2769	**0.4987**
Workspace Availability	**0.6356**	0.0667
Structure Geometry Complexity	0.0913	0.0619
Weather (Hours of Rain)	0.0093	0.2927
Number of Workers	0.0261	0.3868
Length of Workday	0.3585	0.2465

Correlation of determinant, R^2 indicates the degree of relationship between two variables. In this study, the dependent variables are the pre-cast construction labor productivity values, while the independent variables are the factors affecting the pre-cast construction labor productivity. Correlation of determinant, R^2 ranging from +1 to -1 shows significant positive/negative relationships respectively between the variables.

In Table 5, the factors that have strong influence on the productivity values are the factors with higher correlation values. According to the R^2 results, workspace availability shows the strongest influence (R^2 = 0.6356) to the productivity values for AAN project. Meanwhile, for ABM project, the factor highly correlated with the productivity values was the unloading duration of the delivered components. This factor has an R^2 of 0.4987.

Work Hours Breakdown for Pre-cast Construction Labors

Construction is a labor-intensive industry especially in the conventional CIS construction method. Although the pre-cast construction method is less labor-intensive, the installation process still requires the labors. Thus, manpower is one of the main factors behind productivity resources in the construction industry. Hence, construction productivity greatly relies upon human performance (AbouRizk, S. and Hermann U.R., 2001; Hanna et al., 1999; Khaled El-Rayes and Osama Moselhi, 2001; Portas, J. and AbouRizk, S., 1997; Sonmez, R. and Rowings, J. E., 1998).

Labor productivity is improved if more time is spent in value-adding activities. Reducing the share of non value-adding activities is one of the strategies to obtain better productivity. Therefore, it is important to identify the most significant time spent on non value-adding activities as not all non value-adding activities affect the productivity to the same degree.

Table 6 demonstrates the breakdown of time utilization of construction labors (pre-cast structural component installers) at the pre-cast construction site. Data was collected by site observations. The breakdown of non-value adding activities at the pre-cast construction site is shown in Table 7. Move crane is a major non value added activity due to limited number of skilled labor at the construction site.

TABLE 6 BREAKDOWN OF PRE-CAST LABOR TIME UTILIZATION

Pre-cast Labors Activities	Time Utilization
Productive (Direct Installation)	32%
Non-productive	30%
Correction	25%
Delivery (Unloading)	8%
Extra Break	5%

TABLE 7 BREAKDOWN OF NON VALUE ADDING ACTIVITIES FOR PRE-CAST METHOD

Non Value-Adding Activities	Time Utilization
Move Crane	54%
Wait	14%
Idle	13%
Move Component	7%
Clean up	6%
Move Ladder/Equipment	4%
Look for Tool	2%

Productivity Analysis of Conventional Cast In-Situ (CIS) Construction Method

Overview

In this section, the assessment of the construction labor productivity on project utilizing conventional Cast-In-Situ (CIS) method is presented., which is based on a SIRIM laboratory project, a two stories laboratory building consisting of laboratories, seminar rooms, technical rooms, training rooms, etc. This building has a total floor area of 6,000 m² and the major usage of this building is for staff training.

Daily Productivity

The construction labor productivity for conventional Cast-In-Situ method is computed differently from what is done for pre-cast method. In CIS method, the work hour per cubic meter of concrete is calculated as shown in the equation below.

$$\text{Productivy} = \frac{\text{Workhour}}{\text{m}^3 \text{ of concrete}} \quad (2)$$

In this research, construction labor productivity for Cast-In-Situ construction method is measured for the major tasks involved in the construction cycle. For instance, formwork fabrication, reinforcement bar or steel cage fabrication, formwork installation, reinforcement bar installation, concrete placement, formwork dismantle, etc. The productivity measured on the labor performing different tasks is normalized into one term, which is work hour per cubic meter of concrete (wh/m³).

One cubic meter of concrete is equivalent to a structurally completed cubic meter of concrete. Figure 6 below shows the daily productivity values computed for a number of workdays from SIRIM laboratory project.

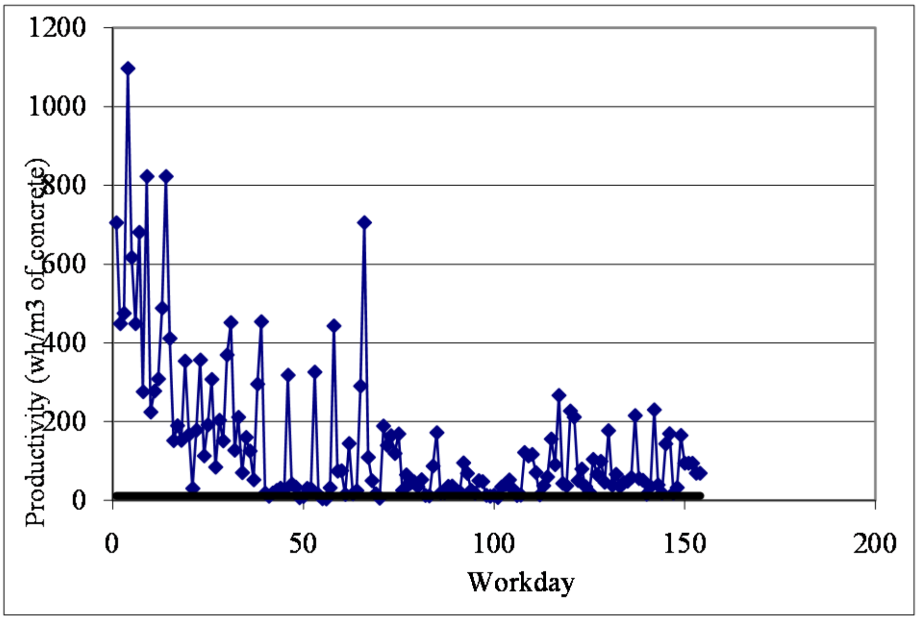

FIG. 6 DAILY AND BASELINE PRODUCTIVITY FOR SIRIM PROJECT

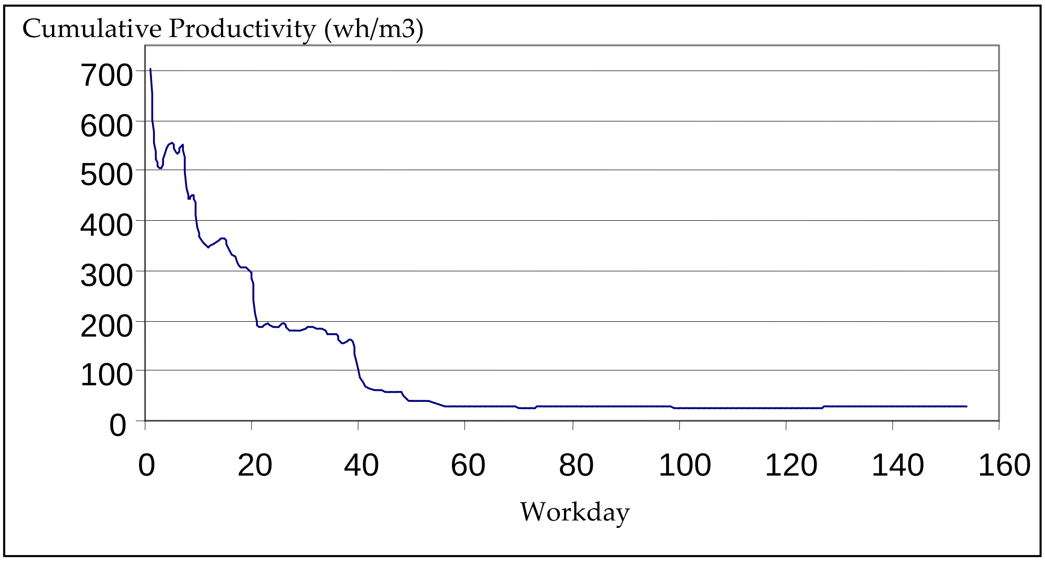

FIG. 7 CUMULATIVE PRODUCTIVITY FOR SIRIM PROJECT

Baseline Productivity

Baseline productivity represents the productivity value when there are few or no disruptions. It also represents the best productivity that a contractor can achieve on a particular project because there are few or no disruptions. This value can be assumed as the highest output. The bold line in Figure 6 indicates the baseline productivity of this project.

Cumulative Productivity

Cumulative productivity is a compilation of all the work hours charged to an activity divided by the total quantities, which is the volume of concrete in CIS construction method context. It can be computed using the following equation:

Cumulative Productivity=Total Work Hours/Total Volume of Concrete (3)

Figure 7 displays the learning curve on the performance of the construction workers. This pattern is expected as the workers will be more skillful on the tasks they have performed so that less time is required to complete similar tasks.

Correlations of Conventional Cast-In-Situ Construction Productivity Factors

The factors affecting the construction labor productivity for SIRIM project using conventional CIS construction method can be quantified by means of Correlation of Determinant, R^2. The values of these correlations for each factor are displayed in Table 8.

According to the correlation of determinant, R^2 results in Table 8, the number of workers is strongly correlated to the CIS construction labor productivity with R^2 equal to 0.7329. This factor is correlated to the productivity values at quadratic relationship, which means that there would be an optimum number of workers that can produce high productivity values. Overall, weather factor (hours of rain) is the second influential factor of the productivity values, followed by complexity of the structure geometry, workspace availability and location of work and lastly length of workday.

TABLE 8 CORRELATION OF DETERMINANT, R^2 VALUES FOR CONVENTIONAL CIS CONSTRUCTION PRODUCTIVITY FACTORS

Factors	Correlation of Determinant, R^2
Structure Geometry Complexity	0.3067
Hours of Rain	0.4270
Number of Workers	**0.7329**
Length of Workday	0.2404
Workspace Availability /Location of Work	0.2451

Work Hours Breakdown for Conventional Cast-In-Situ Construction Labors

Labor's performance or labor productivity is closely related to the worker's time-spent during the work hours. Table 9 below shows the breakdown of time utilization from a group of construction workers in SIRIM project. Data for the analysis has been collected from actual site performance. The percentages shown are based on the data recorded through site observations. On average, nearly 41% of the time spent by the site workers during work hours are productive and the rest of the time is non value-added. The breakdown of time utilization for non-productive site activities is shown in Table 10.

TABLE 9 BREAKDOWN OF CONVENTIONAL CIS LABOR TIME UTILIZATION

CIS Labors Activities	Time Utilization
Non-productive	59%
Productive hour	41%

TABLE 10 BREAKDOWN OF NON VALUE ADDING ACTIVITIES FOR CIS METHOD

Non Value-Adding Activities	Time Utilization
Idle and Wait	42%
Look for Tool/Material	35%
Extra Break	12%
Move Material to Work Place	11%

Summary of the Analysis of Pre-Cast and Cast-In-Situ Construction Methods

Overview

This section summarizes the analysis of the two construction methods: pre-cast and conventional Cast-In-Situand presents the comparison on the daily productivity values and construction labor productivity factors. Furthermore, a few suggestions on the productivity improvements are discussed in this section.

Daily Productivity

Daily productivity for all construction sites had been measured and assessed. Nevertheless, for different construction methods, different techniques had been utilized to quantify the productivity. Thus, they are stated in dissimilar units. Table 11 shows the mean and the standard deviation values computed based on the data collected from each construction site.

TABLE 11 ANALYSIS OF MEAN AND STANDARD DEVIATION

Construction Method	Pre-cast (wh/pc)			CIS (wh/m3)
Project	ABM	AAN	Average	SIRIM
Mean	0.8075	1.1922	0.9999	143.99
Standard Deviation	0.2851	0.7452	0.5152	183.71

Overall, SIRIM project has data with the largest variation from the mean, which is followed by AAN and ABM projects. Thus, it can be concluded that the variability of productivity values for CIS project is worse compared to pre-cast productivity. In another word, the productivity of pre-cast method is consistently better than that of CIS method.

Loss of Efficiency

Labor efficiency in a project is one of the main factors in productivitywhich is because labor efficiency is related to one of the important elements in a project, that is cost. Loss of labor productivity is equivalence to the loss of labor cost that had been paid to the workers. The percent of inefficiency presented in Table 12 is calculated based on the baseline productivity. Overall, it can be concluded that loss of labor efficiency of pre-cast project is less than that of Cast-In-Situ project.

TABLE 12 ANALYSIS OF LOSS OF EFFICIENCY

Construction Method	Pre-cast		CIS
Project	ABM	AAN	SIRIM
Number of Workday	65	60	154
Percent of inefficiency	45%	55%	61%

Correlations of Productivity Factors

Common factors correlated to labor productivity for the two construction methods is presented in Table 13. Structure geometry complexity displays greater impact on CIS construction project compared to pre-cast projects. One of the reasons is that CIS method involves the complete process or cycle at the construction site. A complete process normally starts from the formwork fabrication until the formwork dismantles.

TABLE 13. ANALYSIS OF CORRELATIONS

Construction Method	Pre-cast		CIS
Project	AAN	ABM	SIRIM
Factors	R^2	R^2	R^2
Structure Geometry Complexity	0.0913	0.0619	0.3067
Workspace Availability/ Location of Work	**0.6356**	0.0667	0.2451
Weather (Hours of Rain)	0.0093	0.2927	0.4270
Length of Workday (Overtime)	0.3686	0.2465	0.2404
Number of Workers	0.0261	0.3868	**0.7329**
Unloading Duration	0.2769	**0.4987**	-

For most of the time, the labor performance is affiliated to the location of work and the working space given to them. From the analysis, the effect of this factor is more prominent for AAN project because AAN project is a quarters or hostel building with four floors, whereas the rest two projects are two floor buildings. The effect of this factor on CIS project is also

quite obvious. Thus, it can be concluded that the work space availability and location of work is an important factor for both pre-cast and CIS projects.

Weather, in terms of hours of rain, can be construed as a crucial productivity factor for CIS construction method but it depicts less significant effect on pre-cast method. Length of workday or overtime is the factor that equally influences both construction methods. Although that is the case, the impact is not critical as the correlation values shown are less than 0.5.

Crew size or number of workers that work in a group is interpreted as an important factor for CIS project. Yet, it shows a slight effect on pre-cast projects. Therefore, it can be presumed that number of workers is a crucial factor for CIS method compared to pre-cast method.

Apparently, delivery and unloading of structural components only induces poorer productivity for pre-cast construction method, which is due to multi-tasks performed by the workers or installers that include unloading and installation. Whereas in CIS project, only the raw material deliveries affect the productivity because the unloading job is taken over by the general workers.

In the next section, contractors' perspective on productivity factors is discussed to expand the overview on the construction labor productivity from the practicality point of view.

Contractors' Perpective on Productivity Factors

TABLE 14 RANKING OF PRODUCTIVITY FACTORS

Rank	Descriptions
1	No effect at all
2	Very little effect
3	Little effect
4	More effect
5	Strong effect

The severity in productivity values are caused by numerous factors, no matter how much the effect of the factors on productivity. Apart from the factors showed in Table 13, there are other immeasurable productivity factors. In order to preliminary comprehend the degree of effects of other poor productivity causes; information has been gathered using another approach, which is by distributing questionnaires to each contractor involving in both two pre-cast and CIS projects. Contractors have ranked the factors in different stages followed by the ranking system given in Table 14.

Table 15 presents the result assembled from the questionnaires distributed to the contractors. The factors that ranked higher than 3 are considered to have more obvious effect on the productivity. Data are collected based on the contractors' opinions on the potential productivity factors. Contractors are asked to express their opinions as to what factors or aspects are most likely to contribute to productivity increases and worsening in their projects.

TABLE 15 COMPARISON OF RANKING ON PRODUCTIVITY FACTORS

Construction Field	Pre-cast	CIS
Productivity Factor	**Rank/ Weight**	**Rank/ Weight**
Design Stage		
Design complexity	4.5	3.7
Constructability	4.0	3.3
Component Geometry	3.5	3.0
Size of Component	3.5	2.7
Planning and Management Stage		
Material Availability	2.5	3.3
Material Placement (Material Storage)	3.5	1.7
Tool/ Equipment Sufficiency	2.5	3.3
Tool/ Equipment Condition	2.5	2.0
Resource (Worker) Allocation	2.5	3.7
Delivery Schedule	3.5	3.3
Work Scope Assigned	3.0	3.0
Manufacturing Stage		
Quality of Component Manufactured	4.0	-
Fabrication Error	4.0	-
Site Installation / Construction Stage		
Weather	3.0	4.0
Skills of Labor	3.0	3.7
Labors' Morale and Attitude	3.0	2.7
Absenteeism	2.5	3.0
Crew Interference	2.0	3.0
Tool/ Equipment Availability	3.0	2.7
Work Space Availability (Congestion)	4.5	3.3
Instruction/ Supervision	4.0	4.0
Work Sequencing	3.5	3.7
Repetition of Work (Rework)	3.0	3.7
Safety Condition	3.5	3.0
Length of Workday (Overtime)	3.5	2.3
Length of Work Period (Workdays per week)	2.5	3.3
Location of Work	3.5	4.0

All factors involved during the design stage which are the design complexity, the constructability, the component geometry, and the size of component are crucial factors in determining pre-cast and CIS labor productivity.

Delivery schedule in the planning and management

stage is an influential factor for both construction methods in which material availability, toll or equipment sufficiency and resource allocation are the determinants of CIS construction labor productivity. On the other hand, material placement or material storage is considered as the important factor for pre-cast construction method.

At the manufacturing of structural components stage only pre-cast construction project is affected. The respondents assented that the factors involved in this stage such as the quality of components manufactured and fabrication errors are significant to the productivity values.

During the site installation or construction stage, workspace availability (congestion), instruction and supervision given, work sequencing and location of work are the reasons of poor productivity for both pre-cast and CIS construction projects. Besides that, the productivity in pre-cast construction site is also affected by the causes such as site safety condition, length of workday or overtime and location of work. Furthermore, the factors such as weather, skills of labor, rework, length of work period and location of work display higher impact on the CIS productivity values.

Conclusion

According to the results obtained from this research, it can be concluded that the pre-cast method is better than conventional Cast-In-Situ method in terms of the construction labor productivity. It is shown that the number of work hours to install structural components using pre-cast is less compared to CIS method. The variability of construction productivity in pre-cast method is also small, which means that it has more consistent productivity values over the period of time.

Loss of efficiency during the construction process is also analyzed. It is demonstrated that loss of efficiency in pre-cast method is less as a result of smaller work force at the pre-cast construction sites. The labor efficiency definitely is the main concern in construction as it will effect the total cost incurred in the project.

The baseline productivity for both methods, the unit rates for pre-cast components and the correlation of the productivity factors to construction productivity are presented. These findings can be used as a benchmark to compare with similar pre-cast and CIS construction projects' performance in the future.

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